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Evaluating the cost-effectiveness of invasive alien plant clearing: A case study from South Africa

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ABSTRACT

Conservation projects spend billions of dollars clearing invasive alien plants, yet few studies have measured the cost-effectiveness of doing this, especially over larger spatial and temporal scales, relevant to operational contexts. We evaluated the cost-effectiveness of South Africa's national invasive alien plant control programme, Working for Water, in reducing invasive alien plant cover in the Krom and Kouga river catchments over 7 years. We assessed change in invasive alien plant cover by comparing post-treatment cover with the first recorded pre-treatment cover across all 740 of the two project's treatment sites (ranging from 0.03 to 227.6 ha in size). We also used regression analysis to estimate the effect of predictor variables on the cost-effectiveness of invasive alien plant clearing. We found – by dividing the total costs by the change in invasive alien plant cover – that it cost 2.4 times more (1.5 times for the Krom, and 8.6 times for the Kouga project) to clear invaded land than the highest equivalent estimate made elsewhere. At current rates of clearing, it would take 54 and 695 years to clear the catchments, in the Krom and Kouga, respectively, assuming no further spread. If spread is considered, current control efforts are inadequate, and invasions are likely to continue to spread in the catchments. Pre-treatment invasive alien plant cover and treatment costs per hectare had the greatest positive and negative influence, respectively on cost-effectiveness. Our assessment suggests that invasive alien plant control projects urgently need to monitor their cost-effectiveness so that management practices can be adapted to use scarce conservation funds more effectively.

1. Introduction

Invasive alien plants pose a significant threat to the biodiversity and functioning of the world's ecosystems (Mack et al., 2000; Pimentel et al., 2005); consequently, billions of dollars have been spent controlling them (Pyšek and Richardson, 2011). The most cost-effective approach is prevention, followed by early detection and eradication (Hulme, 2006). When the invasive population is established, biological control can be highly effective for some species and contexts (van Driesche et al., 2010; de Lange and van Wilgen, 2010); however, in most cases, costly mechanical clearing treatments are also required (Pyšek and Richardson, 2011).

Few studies have measured the cost-effectiveness of clearing invasive alien plants over time (Kettenring and Adams, 2011). Furthermore, most studies make measurements over small temporal and spatial scales making it difficult to extrapolate findings that are relevant to operational contexts (Kettenring and Adams, 2011). Having no reliable measurement of cost-effectiveness hampers the optimal allocation of scarce conservation funds (Murdoch et al., 2007; McCarthy et al., 2010). It also makes it difficult to learn from successes and failures, and to adapt accordingly to achieve desired outcomes (Sutherland et al., 2004; Grantham et al., 2011).

Large numbers of alien plant species, including many trees and shrubs (Henderson, 2001), have invaded South African ecosystems (Henderson, 2007; Kotze et al., 2010). Some of these plants reduce scarce water supplies and negatively affect biodiversity and the functioning of riparian zones (Le Maitre et al., 2000; van Wilgen et al., 2008). Growing awareness of the problem resulted in the formation of the government-funded invasive alien plant control programme 'Working for Water' (WfW) in 1995. It is arguably the largest conservation project in Africa (van Wilgen, 2009) and the world's most ambitious invasive alien plant control programme (Koenig, 2009). Unlike other national control programmes that focus on prevention and early detection, WfW spends most of its funds on labour-intensive clearing because, as a public works project, it is expected to create employment in South Africa's impoverished rural areas (van Wilgen et al., 1998; Koenig, 2009).

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Despite its size, WfW appears to be falling short, at a national scale, of the expectation that it would have brought invasive alien plant problems under control within a reasonable timeframe (van Wilgen et al., 2012). Little is known about the cost-effectiveness of its clearing treatments at a project scale, because of a lack of clear, time-based goals, and a system of monitoring and evaluation to assess progress towards these goals (van Wilgen et al., 2012; Levendal et al., 2008). Currently, WfW only records plant cover, treatments and costs on specific sites where contracts are awarded for clearing work. Thus, there is no assessment of the effectiveness of the work done at a landscape scale because only the input variables (money spent, area cleared, and jobs created) are recorded. It is therefore not possible to assess effectiveness in terms of progress towards the goal of restoring ecosystem health.

In a recent national assessment of WfW, van Wilgen et al. (2012) found that despite substantial spending on control operations (3.2 billion South African rands (ZAR) or 432 million US dollars if 1 US$ = approximately ZAR 7.4), the extent of invaded areas in South Africa had grown since the inception of WfW in 1995. Using records of WfW treatment areas, van Wilgen et al. (2012) showed that only a small fraction of the total invaded area was treated. They concluded that WfW should modify its strategy by focussing control efforts in high priority areas (Forsyth et al., 2012). However, the study did not address WfW's cost-effectiveness in reducing invasive alien plant cover at the scale of treatment sites, nor did it explain the factors that influence the cost-effectiveness of treatments.

In this paper, we evaluate the cost-effectiveness of reducing invasive alien plant cover in two of WfW's river catchment clearing projects over 7 years. We based this on a before-and-after evaluation by comparing post-treatment cover with pre-treatment cover across all 740 sites within the two larger catchment areas. We also assessed the variables that had the greatest effect on the cost-effectiveness of invasive alien plant clearing.

2. Methods

2.1. Study area and background to the projects

We conducted our study in the Krom (1556 km^2) and Kouga (2426 km^2) river catchments in the Eastern Cape Province of South Africa (Fig. 1), specifically, in those parts of each catchment where WfW had implemented projects to clear invasive alien plants. These two projects are among WfW's oldest (operating since 1995) and largest in terms of hectares cleared and jobs created.

WfW managers allocate contracts within each project that specifies a treatment site of alien-plant-invaded land that must be cleared within a month. Each treatment site is assigned to a team comprising a team leader (contractor) and 10–15 labourers, recruited from the large numbers of unemployed people in local towns. Each project has, on average, five to seven operational clearing teams at any time.

The principal invasive alien plant species in both catchments is the tree *Acacia mearnsii* (black wattle), native to eastern Australia. When mature, *A. mearnsii* is 5 and 10 m tall. This species is the most prolific invader in South Africa in terms of its spread and impact on ecosystem services (de Wit et al., 2001), and as a result WfW have spent the most money on this species (van Wilgen et al., 2012). Of less importance in the study area are other Australian *Acacia* species, along with species of *Pinus*, *Eucalyptus* and *Hakea*.

The successful control of coppicing species like *A. mearnsii* requires felling, followed immediately by the careful application of herbicide to the cut stems. This kills the plant and thus prevents coppicing. Clearing also stimulates the germination *en masse* of seeds from a large and persistent soil-stored seed bank (Holmes et al., 2008). Numerous and timely follow-up treatments are required to treat both seedlings and coppice re-growth by spraying with herbicide, and is compounded when previous treatments were poorly executed. Re-growth taller than 1.8 m is unaffected by herbicide and plants must be re-felled, which is far more costly (Holmes et al., 2008). During the evaluation period, WfW's policy regarding clearing on private land was that the landowners would agree to maintain cleared sites after WfW's second follow-up treatment.

Both catchments support predominantly fynbos vegetation associated with nutrient-poor, sandy soils that prevail in the area. Fynbos is a fire-prone shrubland (Cowling, 1991) that is vulnerable to invasion by alien trees, even in the absence of anthropogenic disturbance (Richardson and Cowling, 1992). Rainfall is evenly distributed throughout the year in both catchments. The Krom catchment has a higher mean annual rainfall (690 mm) than the Kouga catchment (472 mm) (Schulze, 2008).

The catchments supply 80% of the water for Port Elizabeth, the largest city in the Eastern Cape and an important economic development node in the province. Water is increasingly limiting economic growth in South Africa (Blignaut and van Heerden, 2009), and extensive invasions of alien plants exacerbate this problem

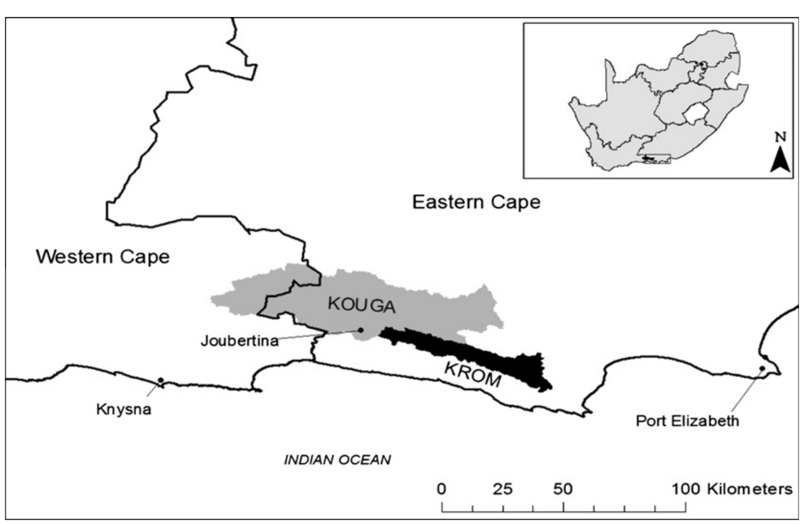

Fig. 1. Location of the Kouga and Krom river catchments within the Eastern Cape Province, South Africa.

(Görgens and van Wilgen, 2004); hence, the implementation of WfW projects in these two catchments.

2.2. Evaluating the cost-effectiveness of invasive alien plant clearing

We measured the cost-effectiveness of invasive alien plant clearing at both a project (either the Kouga of Krom catchments) and site (individual clearing contracts within catchments) level. The site-level data were used exclusively for the regression analysis (see Section 2.4.2). We measured cost-effectiveness by dividing the funds spent on a project or site by the change in invasive alien plant cover (pre-treatment invasive alien plant cover minus post-treatment cover). We converted the estimates of plant cover to 100% equivalent cover ("condensed ha") for comparison across sites, using the formula: $C = d/100 \times A$, where C is the area expressed as condensed ha, d is the% canopy cover, and A is the area in ha that was treated. Our unit of analysis was therefore the cost (ZAR) per condensed ha reduced during the evaluation period.

We assessed the change in invasive alien plant cover by comparing post-treatment cover (December 2008) with the first recorded pre-treatment cover, across all of the 740 treated sites in the two projects (data capture commenced only in 2002, so first records were from 2002 or later). According to the project manager of each catchment, some sites were treated prior to 2002; however, there are no recorded data for these treatments and therefore no way of knowing which sites had been treated. We therefore used the first recorded pre-treatment cover of invasive alien plants as the baseline from which to assess cost-effectiveness. A site was deemed treated if it had been given at least one treatment. The total area treated in both projects was 11,202 ha. The average area of a site was 15.2 ha, ranging from 0.03 to 227.6 ha.

2.2.1. Pre-treatment invasive alien plant cover and costs

We identified treatment sites using WfW's spatially-explicit database, the Working Information Management System (WIMS). Contracts are awarded to clear each site, and WIMS records the spatial boundary of the site, its date of implementation, operational costs, pre-treatment type and aerial canopy cover of invasive alien plants. We included overhead costs (management and implementing agent fees) in the cost estimate, but excluded national WfW management costs as no reliable estimates were available. We inflated all costs to 2010-value ZAR using the consumer price index.

During site assessments, we found that many sites that were recorded as treated in the database were in fact never treated. To account for this, we asked the two project managers to confirm which sites had been treated, and then excluded 103 of the 433 Kouga sites and 17 of the 427 Krom sites from further analysis. Finally, we also checked that the WIMS database had been correctly updated by comparing records with the original hardcopy list of treatments stored by the implementing agent. We added 26 and 63 treatments for the Kouga and Krom, respectively. Thus, we recorded in total 2213 treatments (987 Kouga and 1226 Kouga) on the 740 sites that were treated.

2.2.2. Invasive alien plant post-treatment cover

We estimated the post-treatment percentage canopy cover of invasive alien plants for the three dominant invasive alien plant species present on a site for all the sites using the same methods used to estimate the pre-treatment cover. The methods are based on guidelines related to the type of invasive alien plant, growth form and density (Working for Water Programme, 2003). Because of the large areas involved and the difficulty of estimating cover on the ground, we took aerial photographs of all of the sites from a helicopter, and then made the cover estimates using these photographs. We photographed most (>90%) of the sites in December 2008, and the remainder in February and March 2009.

To ensure that the pre-treatment cover estimates were consistent with our post-treatment estimate, we asked a mapping consultant, who had performed some of the pre-treatment cover estimates in the projects, to give his post-treatment estimate for 28 of the sites we had assessed. He used the same photographs we used to make our estimates. In comparison to his estimates, we underestimated densely covered (50–75%) invasive alien plant sites and closed covered (>75%) sites and slightly overestimated medium (25–50% invaded) and scattered (5–25% invaded) covered sites. For each cover class described above, we adjusted our estimate based on these differences in interpretation.

2.3. Future effort required to complete clearing

We estimated the time and cost that would be required to remove remaining invasive alien plants from both the site and project areas. Because these plants are unlikely to be entirely eradicated from the area, we defined successful removal as a state where the control would only require low-cost maintenance treatments (Marais et al., 2004). We based our estimates on the respective rates of removal and cost-effectiveness achieved in each project during the treatment period (see Section 2.2). For estimating the total cost that would be needed for complete removal, we multiplied our measurement of cost-effectiveness in reducing invasive alien plant cover in each project by the total number of condensed hectares remaining on both the sites and the projects. For the invaded area of the sites, we used our estimate of the remaining (post-treatment) condensed invasive alien plant hectares. For invaded area of the entire project, we used Kotze et al.'s (2010) estimate of condensed hectares of invasive alien plant cover in 2008. We estimated the time that would be needed to clear the remainder of the project areas, by dividing the estimate of remaining invaded area (in condensed ha) by the rate of removal (the average number of hectares successfully cleared per year between 2002 and 2008), assuming no spread. Lastly, we estimated the invasive alien plant spread rate that could be contained by the respective projects. This was calculated by dividing the rate of removal by the estimate of remaining invaded area (in condensed ha). In both the cost and time projections we assumed that future cost-effectiveness would be the same as the historical cost-effectiveness that we measured.

2.4. Factors affecting the cost-effectiveness of site treatments

2.4.1. Data sources

We used the estimated cost to eradicate one condensed hectare of invasive alien plant cover as the response variable in all the models described below. Our analysis only included sites in which invasive alien plant cover had been reduced (pre-treatment–post-treatment cover > 0). This approach led to the exclusion of 217 of the 740 sites where cover had actually increased (36.7% and 20.7% of the Kouga and Krom sites respectively). We selected potential predictor variables based on discussions with nine WfW managers familiar with the project area. We selected variables indicative of biophysical, operational and landowner issues related to the cost-effectiveness of clearing (Table 1). We extracted the operational data from WIMS, and the landowner information from interviews with the managers of each project.

We only selected variables for the regression analysis that had sufficient variation to model its effect on the response variable. We therefore excluded variables related to landowner willingness to do follow-up treatments, tenure type (private versus public) as well as the treatment type used (clearing only versus clearing and native re-planting).

Table 1
Variables used in the single and multiple regression analyses. The response variable is "Cost per condensed ha reduced". Only sites where there was a reduction in alien plant cover (n = 524) were modelled. WIMS = Water Information Management System; NA = categorical variables; ZAR = South African rands; 1 US$ = approximately 7.4 rands.

Variable	n	Min.	1st Qu.	Median	3rd Qu.	Max	Source
Altitude – average (m)	524	200.8	315.1	439.7	600.2	1081	Dept. Land Affairs
Area of all sites on landowner property (ha)	524	4.1	184	322.5	820.6	1194	WIMS
Area of site (ha)	524	0	2.1	7.7	15.8	227.6	WIMS
Cost per condensed ha reduced (ZAR)	524	509	5062	7897	15,970	1,008,000	Assessed
Days since last treatment	524	29	293	790	1120	2249	WIMS
Distance to closest road (m)	524	0	0	2.3	122.3	2904	Dept. Land Affairs
Distance to project office (m)	524	2719	19,610	28,700	38,850	58,150	GIS analysis
Number of treatments	524	1	1.8	3	4	9	WIMS
Pre-treatment invasive plant cover (%)	524	0.6	9.6	33	60	100	WIMS
Pre-treatment invasive plant species	524	NA	NA	NA	NA	NA	WIMS
Project domain (Kouga or Krom)	524	NA	NA	NA	NA	NA	WIMS
Rainfall – annual average (mm)	524	420.3	550.5	670.9	722.1	838.2	Lynch (2004)
Money spent per hectare (ZAR)	524	34.3	785.6	1935	4214	21,030	WIMS
Riparian area (%)	524	0	0	0.1	0.5	1	Dept. Land Affairs
Slope – average (°)	524	0	4.2	8.5	12.7	34.6	Dept. Land Affairs

We estimated the percentage riparian area of a site by buffering perennial and non-perennial rivers by 83 m and 41 m, respectively (Cullis et al., 2007). We used point estimates of mean annual precipitation (MAP) at a 0.01° resolution to estimate site rainfall, and converted these point data to raster data to derive an average MAP estimate for each site.

2.4.2. Regression models of cost-effectiveness

We estimated the individual effect of each predictor variable on the response variable (cost per condensed ha reduced) by using a separate linear regression model for each predictor variable. Both the response variable and each predictor variable were log transformed to improve the fit and ease of interpretation where appropriate (Gelman and Hill, 2007).

We then used multiple linear regression to examine the combined effect of the predictor variables on cost per condensed ha reduced. We used a full stepwise selection analysis (both directions) using Akaike Information Criteria (AIC) to identify the best combination of predictor variables (Burnham and Anderson, 2002). We ran all the above regressions in R 2.13.1 (R Development Core Team, 2011).

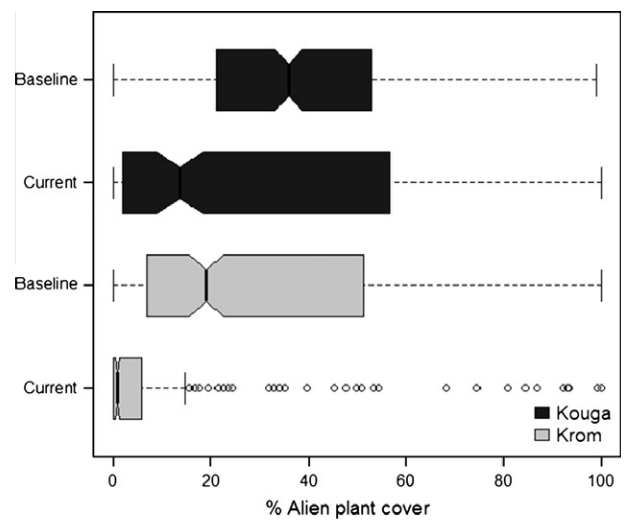

Fig. 2. Distribution of invasive alien plant cover for pre-treatment (baseline) and post-treatment (current) levels on 740 sites treated in the Krom and Kouga catchments in the Eastern Cape Province, South Africa (where boxplot notches do not overlap, medians are significantly different $P < 0.05$).

3. Results

3.1. Effectiveness, treatment costs and cost-effectiveness

The total condensed hectares of invasive alien plant cover across the sites declined from 2013 to 1055 between 2002 and 2008. Most (86%) of this decline occurred in the Krom catchment (Fig. 2). In the Kouga catchment, mean alien plant cover declined only from 888 to 755 condensed hectares, and on 36.2% the treated sites, invasive alien plant cover actually increased despite the clearing effort.

Only 1.4% of the Kouga's catchment area and 5% of the Krom's area were treated, and 97% of these treatments took place on private land. According to the two project managers, none of the landowners contributed to WfW's cost of clearing. In addition, 29% of the landowners followed up on WfW's efforts only occasionally, and 61% not at all, despite agreements to do so.

The bulk of the pre-treatment invasive alien plant cover was made up of *Acacia* spp. (principally *A. mearnsii*) (65.0%) followed by *Eucalyptus* spp. (15.8%) and *Pinus* spp. (13.4%). The post-treatment cover was still dominated by *Acacia* spp. (62.5%), whilst *Pinus* spp. had increased (18.6%) and *Eucalyptus* spp. (3.0%) had declined.

The average amount of money spent on a site was ZAR 2634 (sd. ± 2449) per ha (ranging from ZAR 10 to ZAR 21,031, expressed as 2010-value of ZAR). Overall for both projects, it cost ZAR 20,113 per condensed ha reduced (dividing the total cost by the total reduction in invasive alien plant cover). The Kouga project was far less cost-effective, costing ZAR 70,517 per ha compared to ZAR 11,987 for the Krom catchment. The number of treatments per site ranged from one to nine treatments, averaging approximately three per site.

WfW spent ZAR 19.27 million on the two projects during the assessment period (2002–2008) (Table 2). Most of this cost was made up of operational costs and training for the contractors and their teams (78.3%). The rest was spent on management and implementing agent fees. Labour (workers and contractors) costs

Table 2
Costs of the Kouga and Krom Working for Water projects between 2002 and 2008 (ZAR millions, ZAR = South African rands; 1 US$ = approximately 7.4 rands). National and provincial overhead costs not included.

	Kouga	Krom	Total (%)
Operational costs	7.35	7.75	15.10 (78.4)
Management costs	1.18	1.24	2.42 (9.1)
Implementing agent levy costs	0.85	0.9	1.75 (12.5)
Total cost	9.38	9.89	19.27 (100)

Table 3
Extrapolated time and costs to complete the removal of invasive alien plant-invaded areas at the catchment and site scales in the Kouga and Krom Working for Water projects. Also shown is the invasive alien plant spread rate that the respective projects could contain. The projections assumed current budgets, costs and clearing rates (ZAR = South African rands; 1 US$ = approximately 7.4 rands).

	Catchments		Sites	
	Kouga	Krom	Kouga	Krom
Cost per condensed ha reduced (ZAR)	70,517	11,987	70,517	11,987
Average annual WfW budget (millions ZAR) between 2002 and 2008	1.34	1.41	1.34	1.41
Average annual condensed ha reduced between 2002 and 2008	19	118	19	118
Remaining condensed ha in 2009	13,209	6413	755	300
Years to complete removal (assume no spread) from 2009	695	54	40	3
Total cost (millions ZAR) of removal from 2009	931.47	76.87	53.27	3.59
Hypothetical invasive plant spread rate (%) that could be contained	0.14	1.84	2.52	39.34

represented 30% of the total costs and 40% of the operational costs. Of the money spent on labour, 20% went to the contractor with the rest spent on the team. The remainder of the operational costs was spent on transport, equipment and chemicals.

3.2. Future effort required to complete clearing

Assuming current costs and clearing rates, and no additional spread of invasive alien plants, it would take considerably longer, and cost substantially more, to effectively clear invasive alien plants to maintenance levels in the Kouga than the Krom catchment (Table 3). At the clearing rate of the Kouga project, the WfW programme would only be able to contain the invasions if they spread at a rate of 0.14% or less annually, compared to 1.84% in the Krom project. Both estimates are well below the realistic annual spread rate of 8.5% (Le Maitre et al., 2002). Thus, although the Krom catchment had a higher level of efficiency, both are inadequate to contain spread. Predictably, removal of invasive alien plants from the sites, compared to the entire catchments, would require substantially less time and money. Despite this, we estimate it will still take 40 years to reduce invasions by alien plants from the remainder of the Kouga's treated sites to levels where low-input maintenance would be required.

3.3. The effect of variables on cost-effectiveness of site treatments

3.3.1. Single predictor regression variable relationships

Overall, the single predictor variable models explained a low amount of the variability in cost per condensed ha reduced (Table 4). Mean annual rainfall and the average altitude of a site had the largest effect – positively and negatively influencing the cost per condensed ha reduced, respectively. Pre-treatment invasive alien plant cover, on its own, was not significant and its effect size was relatively small (−0.22% with a 68% confidence interval of ±0.08). Other variables that had strongly significant effects included money spent per ha, distance to project office, number of treatments and pre-treatment invasive alien plant cover.

3.3.2. Multiple regression predictor variable relationships

The predictor variables retained in the AIC-selected model explained a greater amount of variance in cost per condensed ha reduced than the single regression models ($R^2 = 0.67$, d.f. = 516; AIC = 552.59) (Table 5). The variables that had the largest effect on cost-effectiveness were the pre-treatment percentage invasive alien plant cover, followed closely by the money spent per hectare and the average altitude of a site, a proxy for access. To put these estimates into context, holding other variables constant, a site with 25% pre-treatment invasive alien plant cover compared to a site with 50% invasive alien plant cover (i.e. 50% difference in cover) would cost 50.5% (with a 68% confidence interval of ±3.5) less per equivalent condensed ha reduced. Thus if the site with 50% invasive alien plant cover cost ZAR 20,000 per condensed ha reduced, the site with an invasive alien plant cover of 25% would cost ZAR 30,505 per condensed ha with a 68% confidence interval of ±735. Surprisingly with regard to the amount of money spent per ha, after accounting for pre-treatment invasive alien plant percentage cover and site access, a 50% increase in this predictor variable would result in a 49% (with a 68% confidence interval of ±3.6)

Table 4
Single regression models showing the individual relationship between each predictor and the response variable (Cost per condensed ha reduced (ZAR)). Both the predictor and response variables are log transformed with the exception of the categorical predictor variables and the variable "Number of treatments". This transformation allows coefficients to be interpretable as approximate proportional differences for a change in the response variable i.e. a difference of x% in the predictor variable is associated with a difference of the same x% difference in the response variable (Cost per condensed ha reduced) multiplied by the coefficient estimate.

	Intercept	Coefficient estimate	Coefficient std. error	d.f.	Residual standard error	Adjusted R^2	p-Value
Altitude – average (m)	6.20[c]	0.494[c]	0.115	522	1.003	0.032	<0.001
Area of all sites on landowner property (ha)	9.82[c]	−0.105[a]	0.043	522	1.015	0.001	0.015
Area of site (ha)	9.21[c]	−0.0001	0.026	522	1.021	−0.002	0.997
Days between treatments – average	10.62	−0.203	0.123	391	0.004	0.004	0.100
Days since last treatment	9.94[c]	−0.115[a]	0.052	522	1.016	0.008	0.026
Distance to closest road (m)	9.19[c]	0.014	0.014	522	1.019	0.000	0.303
Distance to project office (m)	6.64[c]	0.254[c]	0.068	522	1.007	0.024	<0.001
Money spent per hectare (ZAR)	7.27[c]	0.261[c]	0.038	522	0.978	0.080	<0.001
Number of treatments	8.53[c]	0.225[c]	0.022	522	0.934	0.161	<0.001
Pre-treatment invasive plant cover (%)	8.83	−0.271[c]	0.039	522	0.976	0.084	0.086
Pre-treatment invasive plant species	9.26	NA	NA	518	1.021	−0.004	0.683
Project domain (Krom or Kouga)	9.33[c]	−0.198[a]	0.091	522	1.016	0.007	0.029
Rainfall – annual average (mm)	14.49[c]	−0.818[b]	0.038	522	1.012	0.014	0.004
Riparian area (%)	9.25[c]	0.010	0.013	522	1.020	−0.001	0.419
Slope – average (°)	9.12[c]	0.056	0.031	522	1.017	0.005	0.065

[a] Pr(t) < 0.05.
[b] Pr(t) < 0.01.
[c] Pr(t) < 0.001.

Table 5
Variables retained, via AIC step selection, in the multiple regression model after first regressing "Cost per condensed ha reduced" on the 14 predictors listed in Table 1 (d.f. = 516, adjusted $R^2 = 0.67$, Residual std. error = 0.585, AIC = 552.59, p-value < 0.0001). Both the predictor and response variables are log transformed with the exception of the categorical variables. This transformation allows coefficients to be interpreted as approximate proportional differences for a change in the response variable i.e. a difference of x% in the predictor variable is associated with a difference of the same x% difference in the response variable (Cost per condensed ha reduced) multiplied by the coefficient estimate.

	Estimate	Std. error	Pr(>|t|)
(Intercept)	−6.17	1.626	<0.001
Altitude – average (m)	0.49	0.077	<0.001
Money spent per hectare (ZAR)	0.98	0.036	<0.001
Pre-treatment invasive plant cover (%)	−1.01	0.035	<0.001
Area of site (ha)	0.03	0.017	0.084
Area of all sites on landowner property (ha)	−0.07	0.028	0.014
Distance to project office (m)	0.14	0.046	0.002
Rainfall – annual average (mm)	0.4	0.191	0.037

increase in the cost to remove a condensed ha of invasive alien plant cover. Thus, the amount of money invested into a site did not equate to an improved return on investment.

4. Discussion

4.1. Comparison to existing estimates of cost-effectiveness

Our measurements of WfW's cost-effectiveness were far lower than estimates made in other studies. For example, Marais and Wannenburgh (2008) estimated the average cost per hectare treated as ZAR 3301 (*Acacia* spp.) for dense invasive cover (>75%). Converting this to a condensed hectare and 2010 ZAR it would equal approximately ZAR 4463. Le Maitre et al. (2002) estimated the average cost per condensed hectare ranging from ZAR 2053 to ZAR 8211 (inflation adjusted from 2002 to 2010 ZAR) in an assessment of the economic feasibility of invasive clearing across four catchments. Therefore, our overall estimate was 2.4 times greater than the Le Maitre et al.'s (2002) highest estimate (8.6 times greater for the Kouga and 1.5 times greater for the Krom).

Although our estimates are the highest yet made, they are almost certainly an underestimate, which means that the situation is actually worse than our estimates might suggest. In particular, we excluded sites that WfW recorded as treated, but were in fact never treated. Furthermore, we were not able to include national and provincial costs, nor were we able to evaluate the sites treated prior to 2002 (many of which had been re-invaded according to the two project managers). Estimating the cover from aerial photographs also meant that we could not detect early re-growth via seedling or re-sprouts, leading to underestimates of cover. According to senior managers in the Eastern Cape, the Kouga and Krom are considered to be the most effective projects in the province. Therefore, the projects we evaluated are likely to be more cost-effective than the other WfW projects in the province. The reason that our measurements of cost-effectiveness were so much lower than other studies could be explained by the high post-treatment re-invasion at many of our sites, something that had not been realized in earlier estimates. Our findings of the money spent on treatments were similar to other studies.

The ineffectiveness in reducing invasive alien plant cover has implications for the time and cost required to reduce the cover of invasive alien plants to maintenance levels. For example Marais et al. (2004) estimated, based on clearing rates at the time that it would take between one and 83 years to clear invasive plants from South Africa, depending on the species. This was based on the assumption that no further spread would occur and that only one follow-up treatment would be required. In contrast, we estimated that it would take 695 and 54 years to remove invasive alien plants from the Kouga and Krom catchments, respectively, at current levels of funding. We found that not only are WfW treating only a small part of the respective catchments – an observation consistent with a nation-wide assessment by van Wilgen et al. (2012) – but that where treatment does occur, it is largely ineffective.

4.2. Potential drivers of clearing cost-effectiveness

The amount of money allocated to a site had a negative influence on cost-effectiveness, and one would have expected the opposite. We were not able to assess the quality of treatments carried out, but this unexpected result suggests that adequate levels of diligence are not being consistently maintained. The positive relationship between site distance from the project manager's office and cost-effectiveness could also imply a lack of diligence on behalf of managers in assessing the quality of remote clearing operations. More research would be required to determine the nature of constraints to WfW's ability to implement cost-effective treatments.

The other major determinant of project cost-effectiveness, not accounted for in our regression models, could be the low willingness or capacity of private landowners to conduct follow-up treatments WfW policy regarding interventions on private land is that landowners are contractually bound to take responsibility for site maintenance after the second follow-up treatment carried out by WfW. This did not occur in both the projects that we assessed.

The regression analysis showed that in terms of equivalent condensed hectares, treatments on sites with higher pre-treatment alien plant percentage cover were more cost-effective in comparison to less densely invaded sites. One reason could be that clearing sparse invasions could be more costly than dense ones. This however is unlikely since we controlled for treatment costs. The most likely reason is that since we had no control treatment, we could not account for the spread that would have occurred had there been no treatment. The spread rate is likely to be higher on less densely invaded sites compared to densely invaded ones (Higgins et al., 2001).

4.3. How cost-effective are the projects in the provision of ecosystem services and employment?

In terms of the value of protecting water resources, which was the main argument used for initiating the WfW programme (Koenig, 2009), the high costs of the Kouga treatments suggest low cost-effectiveness in terms of invasive plant control for the provision of water from the catchment area (Le Maitre et al., 2002). On the other hand, the Krom project appears to be far more cost-effective. Underestimating the costs of major interventions, like WfW, is a frequently documented problem in both the public and private sector (Lovallo and Kahneman, 2003). A key remedy to this would be to base forecasts on actual measurements of cost-effectiveness and not solely on estimates which are often prone to optimism bias (Flyvbjerg, 2008).

In terms of the employment benefits, we found that only 30% of the total costs (excluding WfW national and provincial office costs) were spent on team wages; 20% of this went to the team leader. According to Hope (2006), a development project is deemed to be wage-efficient if it spends at least 60% of its budget on wages. The two projects we assessed fell far below this benchmark. Hope (2006) found that 60–65% was spent on the team wages in three WfW projects in the Limpopo province. However, it appears that Hope (2006) only examined the operational costs and did not include the costs of the local implementing agent costs nor those of national management. This implies that low cost-effectiveness in reducing invasive alien plant cover (as observed in the Kouga) cannot be justified solely in terms of the employment benefits. In terms of the quality of employment, Hope (2006) found that the programme did not select the poorest people; the projects made only a small contribution to income (<0.5%) to poor households in the project areas; the employment was highly variable and the workers were not able to find employment after exiting the programme (Knipe, 2005). Some of these issues have already been raised in other programmes implemented as part of South Africa's expanded public works (McCord, 2007). A better understanding is required of the cost-effectiveness of WfW in reducing poverty.

4.4. Prognosis for cost-effective control

Our study identified several problems that, if considered together, indicate that current control efforts are insufficient to prevent the ongoing spread of a serious invasive species, despite significant spending. At best, the rate of spread of invasive species at a catchment scale is only slowed down, not stopped, and in many places spread continues despite clearing efforts. Even if spread could be stopped, at the current rates of clearing it would still take 54 and 695 years to clear the Krom and Kouga catchments, respectively. In addition to this, there seems to be little or no effort on the part of private landowners to maintain cleared land in a cleared state, so the cleared land is simply re-invaded. Some undoubtedly cannot afford it, and others are probably disinterested. We discuss four possible interventions that may help to improve this situation.

The first would be to prioritize that catchments within (for example) a province (Forsyth et al., 2012), and then allocate sufficient funds to the highest priority catchments so that the invaded area could be cleared within a reasonable timeframe. This implies that an investment would have to be made in developing adequate plans for priority areas, and monitoring progress towards annual goals, something that is not currently done. It also implies that, in order to direct sufficient funds to priority catchments, those catchments deemed to be of lower priority would not receive funding. There would undoubtedly be resistance to abandoning clearing projects in lower priority areas, but the alternative would be to continue to operate inefficiently everywhere.

A second intervention would be to invest in improved biological control solutions. In the case of *A. mearnsii*, two biological control agents have already been released (Impson et al., 2011). The first, a seed-feeding weevil, has been able to reduce the seed production of *A. mearnsii* by half (and in some cases up to 78%). The second, a gall-forming fly, was established in 2006. Although it has been slow to spread, efforts have been made to assist the distribution by establishing colonies throughout the range of *A. mearnsii* in South Africa. Where it has become established, "pod production has virtually ceased" (Impson et al., 2011), but it is not yet clear whether the fly will be able to survive in a wider range of climatic conditions. Further options are available. For example, the release of a fungal pathogen on *Acacia saligna* has resulted in "a dramatic decline in population density and longevity of mature trees, as well as a reduction in canopy cover and seed production" (Impson et al., 2011). Similar options would be available for *A. mearnsii*, but because this tree species has commercial value in a small wattle industry, the option has to date not been seriously considered, although it should be (van Wilgen et al., 2011). An economic study of management options for *A. mearnsii* (De Wit et al., 2001) concluded that "the most attractive control option would be to combine physical clearing and plant-attacking biological control with the continuation of commercial growing activities". Under this scenario, commercial growers would have to protect their plantations from biological control agents as they currently do for other pest species.

The third intervention would be to significantly improve levels of professionalism with regard to management. There are several clear areas where a more professional approach would improve the effectiveness of management. These include the allocation of funding to adequate planning, monitoring and evaluation, activities which are currently absent, but should form part of a comprehensive strategy for control (van Wilgen et al., 2011). We also identified significant inefficiencies in the form of inaccurate records, where areas recorded as having been cleared had in fact not been cleared on almost 25% of the sites. There is clearly a need for more effective verification of the quality of work completed prior to payments to contractors. In addition, instead of locating sites for clearing at random (as is presently done), a more systematic approach should be adopted. An understanding of the mechanisms of spread (by means of seeds, mainly along water courses) suggests that a far better approach would be to systematically clear invasions from the top to the lower reaches of drainage courses, to prevent re-invasion of cleared sites from above. The employment of qualified ecologists could thus add an increased level of professionalism to clearing operations.

Finally, it will be necessary to find a more effective way to deal with areas that have been cleared on private land. Although landowners sign agreements to maintain areas that have been cleared once WfW has completed the initial clearing and follow-up, these agreements are, by and large, not honoured. Part of this may be due to landowners simply not having the resources to cope with the required follow-up, and part may be due to the clearing not having been completed to the expected standard before handing back to the landowner. To overcome this, agreements with landowners could be tailored to suit individual situations, instead of adopting a one-size-fits-all approach. Wealthy landowners whose land is relatively lightly invaded could reasonably be expected to maintain the land in a cleared state, while relatively indigent landowners with heavily-invaded properties might reasonably expect a level of ongoing state funding that would bring benefits to downstream water users. Where cleared land is to be returned to the custody of the landowner, the quality and level of clearing should be included in the landowner's agreement, and there should be concurrence that standards had been achieved prior to handover.

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